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Durability Examination of the UHF RFID Labels with Respect to Environmental Changes in Terms of Elevated Temperature and UV radiation

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Abstract

One of the key points of interest of sustainability is the preservation of products in order to make full use of their predicted lifespan. In that sense UHF RFID labels are no different. UHF RFID labels have replaced traditional labels in a wide range of products, from unique luxury products to commercial packaging. The reason lies primarily in economy. Namely, tagged products are easy to track throughout the entire production and supply chain. The question arises as to what extent the quality of the label is affected by exposure to different environmental conditions within production and distribution chain process. To this end, durability of the UHF RFID labels with respect to environmental changes were examined. Samples were exposed to electromagnetic radiation (artificial aging for 48h and 96h) and elevated temperatures (50 °C and 60 °C). Changes in the conductivity and read range frequency of the UHF RFID label antennas were determined. In order to get an insight into the degree of degradation, image analysis of the samples was performed with the Personal IAS imaging device.

Key words

degradation, imaging, UHF RFID labels

1. INTRODUCTION

One of the key points of interest of sustainability is the preservation of products in order to make full use of their predicted lifespan. In that sense UHF RFID labels are no different. RFID labels are more and more present in the everyday life and have a wide range of applications that include manufacturing (inventory control, inventory management), different transport processes (shipping, vehicle tracking, supply chain logistics and distribution, livestock tracking), healthcare (equipment tracking, medication tracking), security systems, retail sales etc. Different areas of use imply the need for certain characteristics of labels primarily in relation to their durability caused by different ways of storage and transport of labeled products.

In order to address the durability and longlivity of UHF RFID tags we must first get acquainted with the basic concepts of RFID technology. RFID tag is constructed from two elementary parts (the chip and the antenna). If we want to simplify things, we can say that the chip is a miniature computer, while the antenna is a way of communicating between the chip and the reader. Two types of tags can be distinguished, active tags (having their own energy source) and passive tags (communicating when put in an electromagnetic field). The simplest way of explaining how the RFID communicates with the reader is when the reader emits an electromagnetic wave of a specific frequency it interacts with the RFID which in the end results in the back scattering at a frequency that carries information about the chip [1]-[3]. RFID tags come in various shapes and forms.

In our work we concentrated on the influence of environmental conditions on the longlivety of the UHF RFID tags used for labeling in one of the major sporting goods retailers-Decathlon. Decathlon sells more than 600 million individual products every year through a network of more than 1500 stores in Europe, Africa, South America and Asia [4].

Decathlon integrated their RFID solution in each step within their supply chain allowing enormous benefits of this strategy in their factories, distribution centers and stores. They started tagging all of their own branded products at the manufacturing plants already in 2013. The procedure included placement of RFID labels on items during the manufacturing process. Each RFID label was encoded with a unique identification number stored in the retailer's database.

Decathlon suppliers use handheld RFID readers inside their factories to record and track the transport of products to the distribution centers. The main advantage of RFID identification lies in the ability of making the tracking process easier and faster which in turn reduces the risk of error. Upon the arrival at a distribution center the products' ID is read from the RFID tag and recorded using fixed RFID readers, after which the products are stored for the picking process. Products that are not made by Decathlon and were not tagged at the factory are tagged with an RFID label at the distribution center. In total, more than 85% of products are RFID tagged [5].

Regarding the operation of RFID labels, they are printed and afterwards encoded with a unique identification number. Once the products that were tagged during production are received and the other branded products have been RFID tagged, several types of RFID systems, including mobile readers and RFID reading tunnels, are used to perform cycle counts and shipping control. Decathlon can ensure that the right products are shipped to the right stores.

Upon the arrival at the store, the products are placed on display shelves ready and available for consumers. Store personnel use an RFID handheld reader connected by bluetooth to a smartphone in order to execute efficient shelf inventories which are almost five times faster than with the former systems and technologies. Decathlon keeps up with the wishes of the consumers by installing RFID based check-out systems in order to make the payment process quicker and easier. The system consists of an RFID reader embedded into the check-out table. When a customer wishes to check-out, the cashier simply passes the products across the top of the table to read the product RFID ID encoded into the label without having to use a traditional barcode system [5]. The retailer also installed EAS-RFID gates at the stores entrance as a security measure. Namely, when passing through the gates, RFID tags are detected, so the system can check if the products have been purchased or not, and then alert the security staff.

Storage conditions were the RFID labeled products are held can very drastically with respect to the geographical location of the store, quality of the storage building as well as unexpected extreme conditions during transport. In that sense the question arises in what way the environmental changes, especially elevated temperature and UV radiation impact the quality of the UHF RFID label

2. MATERIALS AND METHODS

In our research we will examine passive UHF RFID tags. Namely, Decathlon uses the Tageos 100% paper-based passive UHF RFID tags.

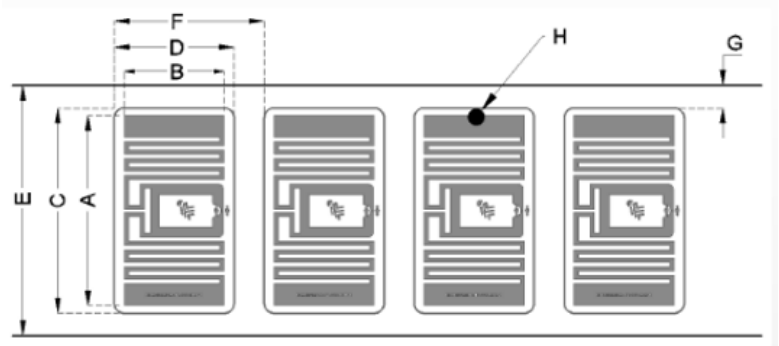

Figure 1. Tag 1[6]

Table 1.Dimensions of tag 1[6]

Dimensions	**A x B**	**C x D**	**E**	**F**	**G**	**H**
Description	Antenna size	Label size	Web width	Pitch	Die-cut to web edge	Bad mark
Metric/mm	38 x 20	41 x 24	50	30 ± 0.5	4.5	4

The labels have been specifically designed for Decathlon in order to match the various types and sizes of product items to be tagged. Two types of tags were analyzed. For simplicity, we will label them as Tag 1 and Tag 2. They come in a specific format as a double sticker. General characteristcs are the same for both tags. They operate in ETSI 865–868 MHz frequency under EPC Class 1 Gen 2 protocol. Antenna is made out of aluminum. Front face material is white printable paper while the adhesive used is solvent-free permanent acrylic adhesive [6,7]

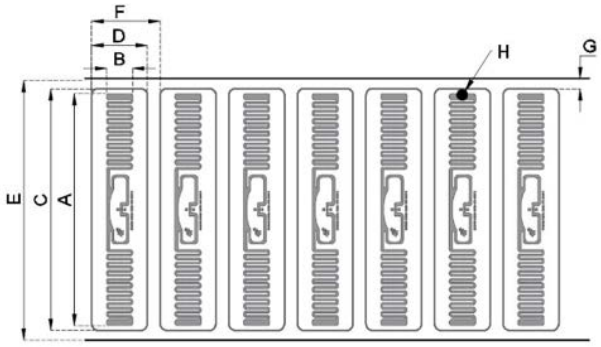

Figure 2. A sample line graph using colors which contrast well both on screen and on a black-and-white hardcopy [7]

Table 2.Dimensions of tag 2[7]

Dimensions	**A x B**	**C x D**	**E**	**F**	**G**	**H**
Description	Antenna size	Label size	Web width	Pitch	Die-cut to web edge	Bad mark
Metric/mm	71 x 8	74 x 17	80	21 ± 0.5	3	4

Samples were exposed to electromagnetic radiation in Cofomegra Solarbox 3000 Xenon Test Chamber. (artificial aging for 48h and 96h) according to ISO standard. Also, given the very high temperatures in which the labels/products are stored and transported, we also tested the effect of the elevated temperature, 50 °C and 60 °C, respectively, by exposing the samples in the "Kottermann" air chamber Type 2306 for 48 h and 96 h at 40% relative humidity.¸

Changes in the conductivity and read range frequency of the UHF RFID label antennas were determined according to the research presented in [2].

From the measurements conductivity was computed according to

$$\sigma = \frac{l}{R \cdot t \cdot w} \tag{1}$$

where l stands for length, w width, t depicts thickness and R is the resistance obtained from current voltage measurement.

In order to get an insight into the degree of degradation, image analysis of the samples was performed with the Personal IAS imaging device. It consists of a measurement head housing a high performance digital camera and an optical modules. The justification for using an analysis device has been discussed earlier in numerous articles [8,9]. The standard optical arrangement is 45/0 geometry, typical for reflective, densitometric measurements. PIAS-II analysis results are displayed in both numerical and graphical form. The user can display contours, bounding boxes, center marks, and ROIs for the image features analyzed.

3. RESULTS AND DISCUSSION

Exposure of the tags to elevated temperatures and UV radiation had no impact on the read range regardless of the tag type. Also, no change in the conductivity of the antennas in both tag types were detected. Mean value of the

conductivity of all tags, before and after the experiment, corresponds to $\sigma=(3.3\pm0.2)\cdot10^7$ S·m^{-1} indicating electric stability of UHF RFID tags.

Even though the tags showed great electric stability, image analysis indicated changes related to degradation of front face material which is white printable paper and the adhesion of the tags solvent-free permanent acrylic adhesive. In Fig. 3. pictures of Tag 1 after exposure to UV radiation for 48 h and 96 h are given. Degradation of the adhesive is evident, resulting in exposed antenna.

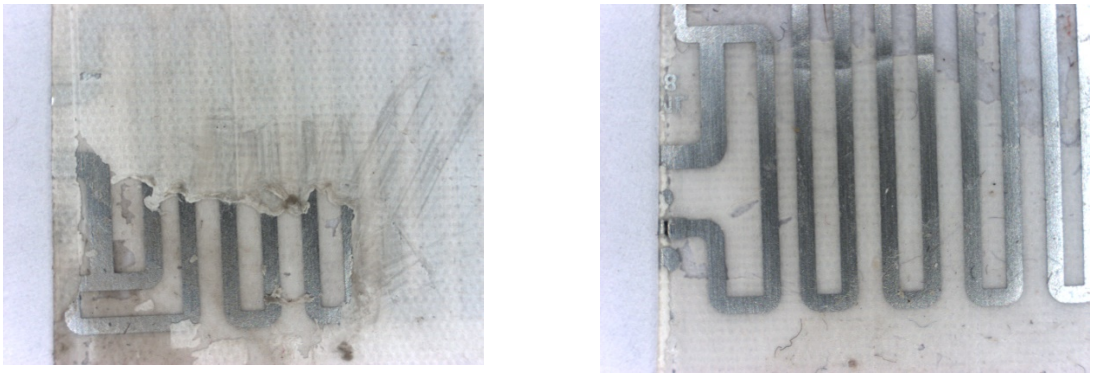

Figure 2. (a) Tag 1 after exposure to UV radiation for 48h (b) Tag 1 after exposure to UV radiation for 96h

Table 3. Summary of the results obtained by Pias for Tag 1 after exposure to UV radiation for 48h

Line Summary	Mean	Min	Max	Stdv
Width / mm	0.713	0.645	0.781	0.03
Min width/mm	0.62	0.403	0.756	0.123
Max width / mm	0.87	0.832	0.928	0.033
Std Dev Width / mm	0.053	0.018	0.114	0.033
Fill	0.973	0.971	0.975	0.03
Contrast	0.502	0.429	0.554	0.052
Density	0.475	0.43	0.504	0.027
Reflectance	0.336	0.313	0.372	0.021

If we compare the summary of the results obtained by Pias for Tag 1 given it tables 3 and 4 it can be seen that the mean line width corresponds to 0.71 mm in both cases. Line fill, contrast and density dropped slightly, while the reflectance increased all of which corresponds to the removal of the adhesive layer from the label. The lack of the adhesive may eventually cause the label to drop from the product which means that products should be handled with care in case of any increased exposure to UV radiation in transport and storage.

Tag 2 showed less pronounced changes in the appereance in respect to the exposure to elevated temperatures (Fig. 5. And Fig. 6.) that can occur during the transportation process. The level of degradation to the adhesion layer and paper substrate was significitally lower compared to degradation caused by UV radiation which means that the products are relatively well protected in closed dark compartments during the transport process. Degradation of the paper base and the adhesive, although undeniably present, are not the cause for concern when considering label decay.

Table 4. Summary of the results obtained by Pias for Tag 1 after exposure to UV radiation for 96h

Line Summary	Mean	Min	Max	Stdv
Width / mm	0.712	0.641	0.783	0.153
Min width/mm	0.023	0	0.047	0.014
Max width / mm	1.002	0.709	1.589	0.245
Std Dev Width / mm	0.188	0.122	0.354	0.067
Fill	0.963	0.908	0.987	0.028
Contrast	0.489	0.295	0.589	0.107
Density	0.427	0.274	0.519	0.092
Reflectance	0.383	0.302	0.532	0.085

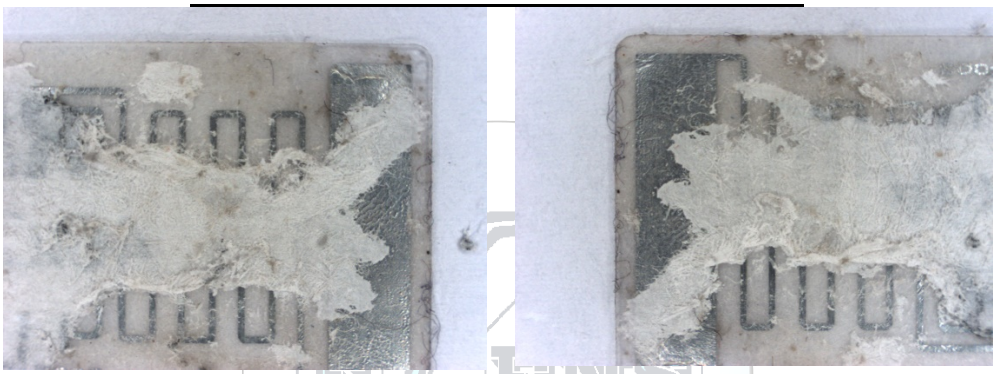

Figure 4. (a) Tag 2 after exposure to 50˚C (b) Tag 2 after exposure to 60˚C

If the data obtained by Pias for Tag 2 (Table 5 and Table 6) are closely inspected, it can be seen that the values for fill and contrast decrease for 3 % and 6 % when the temperature is increased from 50˚C to 60˚C. At the same time the value of density dropped for 11 % while the reflectance increased for 11 %.

Table 5. Summary of the results obtained by Pias for Tag 2 after exposure to 50˚C

Line Summary	Mean	Min	Max	Stdv
Width / mm	0.276	0.231	0.31	0.028
Min width/mm	0.059	0.015	0.135	0.04
Max width / mm	0.511	0.331	0.7	0.146
Std Dev Width / mm	0.104	0.08	0.14	0.019
Fill	0.973	0.925	1	0.029
Contrast	0.502	0.453	0.588	0.044
Density	0.479	0.402	0.554	0.051
Reflectance	0.334	0.279	0.396	0.039

Table 6. Summary of the results obtained by Pias for Tag 2 after exposure to 60˚C

Line Summary	Mean	Min	Max	Stdv
Width / mm	0.262	0.212	0.284	0.024
Min width/mm	0.077	0.026	0.187	0.052
Max width / mm	0.356	0.324	0.405	0.027
Std Dev Width / mm	0.084	0.033	0.108	0.025
Fill	0.948	0.829	1	0.06
Contrast	0.436	0.282	0.558	0.102
Density	0.366	0.234	0.492	0.094
Reflectance	0.44	0.322	0.583	0.096

Although the layer of paper has largely remained fixed to the antenna it is obvious that this inequality in surface coverage in respect of the amount of adhesive and paper affects the changes in density and reflectance.

4. CONCLUSION

In our research we examined the influence of UV radiation and elevated temperature on two types of UHF RFID labels commercially used in one of the worldwide present sporting products retailers. Our results showed that the exposure of RFID UHF labels to electromagnetic radiation had no influence on the read range and conductivity of the UHF RFID tags. At the same time image analysis showed the decrease in the longlivity of the adhesion between the RFID tag and the substrate. UHF RFID tags show satisfactory quality in regard to their electrical properties, but there is a place for improvement in the substrate/adhesion materials.

It is evident that there are multiple advantages and benefits of using RFID tags as labels. One of the key points are the upgrades in inventory tracking in connection much faster and more efficient inventory. No less important, timely procurement and redistribution of products from distribution centers to stores was made timely. Thanks to the RFID tagging of every product, a full store inventory can be performed as often as necessary with a rather small number of personnel. Any improvements in the quality of the adhesive and tag substrate will only improve this process even more as it will mean a smaller amount of destroyed / damaged labels..

CONFLICT OF INTEREST STATEMENT

The author(s) declare(s) that there is no conflict of interest.

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